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No. XVIII.

CENTERING FOR LARGE STONE ARCHES.

The GOLD VULCAN MEDAL was this session presented to Mr. ALFRED AINGER, of Everett-street, for a design for Centering to large Stone Arches. A model is placed in the Society's repository, and the design is further explained in the following communication.

SIR,

Everett-street, Oct. 15, 1821.

THE construction of a centre for large stone arches has been considered one of the most difficult tasks which the art of carpentry imposes. The merits, both actual and comparative, of those which have been used during the last century, have been frequently discussed, and successive attempts at improvement have alternately been corrected by failure and confirmed by success.

Much novelty is not to be expected in a subject to which science, experiment, and ingenuity have long been specifically directed; a subject involving few principles, small variety of circumstances, and little choice in the materials to be employed. The present design, therefore, advances little pretension to originality, and its peculiarities will be best understood by a comparison with that of the centering employed in Waterloo-bridge, which it most nearly resembles, and to the real or supposed defects of which it owes its existence.

Those defects consist in—

I. The numerous *halvings*, and other sources of weakness, to which the main timbers were subjected by their repeated intersections.

II. The great obliquity of many of the timbers to the direction of the pressures they sustained.

III. The absence of any effectual means of tightening the several parts of the frame, and of closing the abutments previously to the action of the load.

With respect to the first of these, it will be admitted, that *halving*, or otherwise seriously wounding a main timber, is a great evil; for whether the strength of prisms vary with the squares, or cubes, or biquadrates (as different theories give it) of their homologous sides, an immense loss of strength is incurred, together with a destructive expenditure of labour and material. It is much worse when the halvings are many times repeated, and worst of all when they are on opposite sides of the timber at small intervals, for then the strength of the piece is limited to the lateral cohesion of the wood between the two halvings, and its liability to bend or break is increased in an alarming degree.

In a design for a roof, of whatever span, or to support whatever load, a proposition to halve the principal rafters would be deemed injudicious, and means would be sought to avoid its necessity. To do this can be no less desirable in the case of centering, which is required to sustain so much greater pressures, and to embrace so much wider openings; in which also permanence of form is of so much greater consequence, affecting as it does the pre-

servation of the curve, and the adjustment of the joints of the superstructure.

A reference to the engraving, Plate XVI. fig. 1, will explain the disposition of the timbers, by which it is proposed to avoid the first of the defects before enumerated. The principal timbers *sb sc sg kc kg* and *kh* are nowhere halved, or in any way weakened, except by the small inconsiderable mortises which contain the tenons of the radial pieces *br*, &c. At their only place of intersection *o* they are received against a cast-iron block, which is shown on a larger scale in an outline elevation at fig. 2, No. 1, and in a shaded section at fig. 2, No. 2. This block, as well as the shoes *aiks*, is adapted to receive the whole sectional area of the timbers at right angles to the direction of pressure; its weight is reduced by apertures, which are not shown in the engraving, and the shoes are tenoned and bolted to the sole pieces *as ik*. The rib pieces *ab bc*, &c., are bolted to oak or elm knees in the usual manner.

With respect to the second object, that of diminishing the obliquity of the timbers to the direction of the pressures they sustain, it is included in the same arrangements which avoided the numerous intersections, and which consists principally in withholding any direct support from the points *def*, and in giving to them an indirect support, transmitted from the points *c* and *g*, by means of a system of wrought iron rods formed and applied in a peculiar manner. These rods, in addition to the purpose just mentioned, give a power of tightening and exciting any part of the frame, the absence of which constituted the third real or supposed defect in the centres of Waterloo-bridge, and in all that have been hitherto made.

This defect requires, therefore, to be now more particularly noticed ; and, as in the first case, the impropriety of halving main timbers was illustrated by reference to the construction of a large roof, so may the value of the power which it is now, for the first time, proposed to give to large centres, be enforced by a similar allusion. The great object in all timber constructions is to resolve the area of the frame into a judicious series of triangles ; but after this has been done, and the timber accurately fitted together to represent those triangles, it will be found, on being loaded, to yield ; the triangles will all become smaller, and the frame will break, or suffer a derangement. This is occasioned by the unavoidable imperfections of the material on which, and of the implements with which, the carpenter is obliged to operate. The hardest timber will yield under a considerable pressure, and the most perfect workmanship will not insure contact at all the points of two opposing surfaces. To overcome this yielding, therefore, and to increase the number of touching points previously to the action of the load, is the object of the carpenter in every instance except that of centering. He accomplishes this object generally by causing each triangle to consist of two sides in a state of compression, and one in a state of extension, as in the common roof, and then, by forcing the middle of the extended side towards the intersection of the compressed sides, he subjects the frame to a strain, more or less, nearly similar in nature and intensity to that which it will sustain in practice. In none of the common operations of carpentry is this precaution omitted ; trussed girders, partitions, and roofs, are always fixed in their places in a state of great excitement ; the absolute necessity of doing

so has never been doubted, and an attempt is now made to extend the benefit of a similar proceeding to the centres for large arches, and even to such of these as are framed with a view to preserving the greatest possible height above the water-way.

With this view, therefore, in conjunction with that of supporting the points *def*, the system of iron rods has been applied. At *c* and *g* are placed cast iron saddles (shown in a section and bird's-eye view at fig. 4), from which proceed the rods *cs gk*, attached at each end to bolts resting on the saddles or passing through the shoes *s* and *k*; from the same saddles proceed two other rods *co go* meeting on a common bolt in the centre, and continued on to the timber, where they are wedged and keyed, as shown at *yy* in fig. 2, Nos. 1 and 2. Previously, however, to wedging at *yy*, the rods are brought to any required degree of tension by means of wedges *t* driven above the middle bolt *x*, by which it is forced downwards in an aperture formed for that purpose in the cast-iron block. The bolts which receive the upper ends of the rods just described are connected at the saddle by wrought iron loops *vv* (fig. 4). From the middle bolt *x* proceed two other series of smaller rods, terminating at bolts in the shoes *s* and *k*; and from each of the two bolts in the saddles *c* and *g* also proceed two series of small rods meeting at *e*, or ending in bolts fastened to the smaller shoes *a* and *i*. It is hardly necessary to explain, that there is a precisely similar arrangement of rods on the other side of the timber. The smaller rods are received at their intersections *brgdpe*, &c. on bolts resting in the semi-cylindrical cavities of cast-iron bearing plates, as shown at fig. 5.

Between the timber and each of the cast-iron plates at $l m n p q$ and r , two pairs of oak wedges, side by side, are introduced, which, together with the iron wedges at t , constitute the means of tightening and exciting in any degree, any or every part of the frame. In consequence of using two pairs of wedges, each cast-iron plate becomes susceptible of a universal motion, by which a precisely equal degree of tension may be communicated to all the rods, independently of small differences in their length, or of any common irregularities in the timber or castings.

It remains now to describe the other object of the iron rods; namely, the transmission of part of the support obtained at c and g to the points $d e$ and f . Inasmuch as the points c and g cannot approach without crushing the pieces of the rib $c d d e$, &c. or closing their abutments (which abutments, if not close in the first instance, may be secured by the insertion of their wedges), the intersection o of the rods $c o g o$ cannot descend till some part of the rods $s c c o k g g o$ stretches or breaks; and as the force which a given load at e will exert towards producing this effect is easily estimated, the rods in question may, without difficulty, be made adequate to the required resistance, and the point e may be effectually sustained by the intervention of the vertical piece $e o$. In like manner d and f will be sustained by the rods $c p p e$ and $e n g n$ through the intervention of the radial pieces $d p f n$ which may be connected together on each side of the braces $c o g o$ by cast-iron clips to prevent the necessity of weakening those braces by large mortices. This plan was adopted in the model on which the experiments hereafter to be described were made; though, on account of the smallness of the scale, they are omitted in the engraving.

The wrought-iron rods which I have been describing, discharge a third duty of not less importance in an economical view than those which have been already noticed; they supersede the necessity of any bolts, straps, or ties, used merely as means of connection; and thus the whole quantity of iron in this design, notwithstanding its extensive use as a means of support, would not be more than half of the quantity employed in the centres of Waterloo-bridge, where it fulfilled no other purpose than that of uniting the several parts of the timber frame.

Having said that the support of the points *def* is to be derived from *c* and *g*, it may be necessary to allude to the adequacy of these latter to afford that support, in addition to sustaining that portion of the arch stones immediately above them. Their sufficiency in this respect is easily shown by calculation, has been proved by experiment, and may thus be inferred. In the centres of Waterloo-bridge each of the points *def* was supported by two braces extending to the extremities *s* and *k*. Those meeting at *e* would receive the weight of the arch-stones between the numeral letters IV and V. Now a very rude resolution of the forces at *c* and *e* will show, that with equal loads the pressure on braces in the direction *ek* or *es* would be nearly equal to that on *cs*, opposed as it is by *ck*, on which the pressure would, by the same resolution, appear to be half of that on *cs*. But the direct and transmitted loads on *c* are together little more than double that which rests on *e*; therefore *cs* will receive a pressure not much more than double, and *ck* a pressure not much more than equal to that which *es* or *ek* would sustain. But *cs* and *ck* are whole timbers, on

which account alone they are many times stronger than es and ek , repeatedly and necessarily halved and mutilated. Then cs , which sustains the greater load, is very short, and in this gains an accession of strength, added to which, its nearly vertical position removes any considerable tendency to overthrow the pier. There can, therefore, be no doubt of the stability of the points c and g , without calculating on any assistance from the braces os ok , or on the support which would be transferred to c and g from b and h , by the rods bq hm .

The requisite size of the rods is a matter of calculation; it is proposed that sc co , &c. have a section of three square inches, all the others of one square inch.

A centre according to the above description would contain not more than one-third of the timber, and not half the iron consumed in those of Waterloo-bridge*. Such a diminution of material, if it can be safely effected, gives rise to a second series of advantages, among which economy, facility of setting and striking, accuracy of workmanship, and the avoidance of personal danger, would be conspicuous.

Whether so great a reduction be practicable, whether there be objections to so extensive and important a use of iron, nothing perhaps but experience on the large scale can satisfactorily determine.

The following is a detail of experiments made in presence of the Committee of Mechanics, on a model adapted to a semi-elliptical arch, having a span of fifteen feet and a versed sine of four feet four inches and a half. The

* From the best information I have been able to get.

load consisted of pig iron previously weighed and marked, which was placed in scales suspended by stirrup irons from the points I, II, III, IV, V, VI, VII, and VIII*. An index was affixed to mark the changes in the form of the model, and the progress of the load made to represent the actual erection of a bridge. Inasmuch as the model was adapted to an arch one-eighth of the size of those in Waterloo-bridge, one sixty-fourth of the actual weight sustained by those centres is the largest that should have been applied to the model. This would give for each of the points—

	Lbs.
I and VIII, about.....	600
II and VII, about.....	900
III, IV, V, and VI, about.....	1200

making a total of 7800lbs. The load actually applied exceeded 19,000lbs.; before describing which particularly it must be stated, that the stirrup-irons suspended from I and VIII were connected at the lower extremities by horizontal rods, which constrained them to take a direction parallel to *br* and *hl*. Those at II and VII were in like manner drawn into lines parallel to *cq* and *gm*. This constraint on the irons I and VIII, II and VII, caused the weights in the former to exert a pressure one-third, and in the latter one-fourth, greater than their actual value.

The following account of the progress of the load and

* For the opportunity of making these experiments, and for much valuable assistance in performing them, the Society is indebted to the liberality of Messrs. Lees, Cottam, and Hallen, in whose premises they were made and repeated.

its effects is extracted from the minutes of the committee:—

	Lbs.	
No. I was loaded with ...	714	} No sensible change.
VIII.....	740	

The angle formed by the stirrup irons, Nos. 1 and 8, was such, that on resolving the forces the diagonal representing the actual force was 21, and the side representing the strain on the stirrup 27. The actual strains, therefore, on the stirrups, were between 900lbs. and 1000lbs.

The former loads being retained,

	Lbs.	
No. II was loaded with...	1240	} No sensible change.
VII.....	1256	

For reasons similar to the former, these weights were equivalent to 1500lbs.

The former loading all retained,

	Lbs.	
No. III was loaded with	1075	} No appreciable change.
VI.....	1111	

The former loading still retained,

	Lbs.	
No. IV was loaded with...	212	} The middle had now sunk twice the thickness of the line, or about 2-30ths of an inch.
V.....	310	
No. IV was then increased to	1311	} The whole weight was now 8787lbs. and the middle had sunk three-sixteenths of an inch.
V.....	1340	

It was now determined to try the effect of a still more excessive load on the haunches; for which purpose the loads were removed from Nos. II, III, IV, V, VI, and VII, and the bolts which had hitherto confined the model to the abutting pieces were cut away, in order to ascertain whether there was any tendency to slide up or down the inclined planes which supported the soles *as i k*.

	Lbs.	
No. I was increased to...	1932	} The strains in the direction of the stirrups, produced by these loads, would be for each about 2500lbs.
VIII	1915	

There appeared, however, no tendency to slide on the abutments, but the crown rose one-tenth of an inch. The weight was now five or six times greater than could occur in practice, while there was nothing at the crown to represent the weight of the centre itself, and of the planking, bracing, and other extraneous matters. The first applied weights of 714lbs. and 740lbs. produced, as before stated, no effect.

The loads were afterwards increased till they were as follows :—

	Lbs.		Lbs.
I	1932	equal to	2500
II	1840		2240
III	2406		2406
IV	2173		2173
V	2340		2340
VI	2261		2261
VII	1870		2280
VIII	1915		2500
Total..	16737		18700

No alarming symptoms of distress were exhibited, and the model remained uninjured. The index had been accidentally deranged during the application of these last weights, and of consequence the greatest depression was never ascertained.

I am, Sir,

A. Aikin, Esq.

&c. &c. &c.

Secretary, &c. &c.

A. AINGER.